

**ORIGINAL RESEARCH ARTICLE****Pyrethrum marc rates and intra-row spacing influence on selected soil chemical parameters and yield of bush bean (*Phaseolus Vulgaris L.*) grown on andosol under rainfed conditions****Munyampundu Emmanuel¹, Rukangantambara Hamudu¹, Habimana Sylvestre¹, Rutayisire Théoneste¹, and Niyonkuru Rose¹**¹College of Agriculture, Animal Sciences and Veterinary Medicine (CAVM), University of Rwanda, RwandaCorresponding email: munyemma1983@gmail.com**ABSTRACT**

Bush bean is an important pulse crop that enriches the Rwandan diet and is a source of cash. This staple crop is widely grown in Rwanda. However, the improper spacing and inadequate application rates of organic inputs result in low yields. The purpose of this study was to evaluate the effect of intra-row-spacing and pymarc application rate on selected soil chemical parameters and bush bean (*Phaseolus Vulgaris L.*) yield on andosol under rainfed conditions. The experiment included five pymarc rates with four replications in a randomized complete block design: P0(No fertilizer), P1(250 kg ha⁻¹ of NPK), P2(10 t ha⁻¹ of pymarc + 250 Kg ha⁻¹ of NPK), P3(15 t ha⁻¹ of pymarc + 250 Kg ha⁻¹ of NPK) and P4(20 t ha⁻¹ of pymarc + 250 Kg ha⁻¹ of NPK) and 3 spacing levels: S1(40 cm x 15 cm), S2(40 cm x 20 cm) and S3(40 cm x 30 cm). The results indicated that a significant difference was found between treatments and their interactions except for pH ($p < 0.05$). Regarding pymarc treatments, P4 contained greater amounts of organic C(5.30 %), total N(0.30 %), available P(56.70 ppm), available K(81.30 mg dm⁻³), exchangeable Ca(12.61 Cmol Kg⁻¹) and Mg(5.0 Cmol Kg⁻¹) at harvesting compared to P0 and P1. According to plant spacing, S3 held higher amounts of OC(4.85 %), av. P(55.15 %), av. K(60.94 mg dm⁻³), exch. Ca(11.0 Cmol Kg⁻¹) and exch. Mg(3.6 Cmol Kg⁻¹) than S1. There was an interaction effect of pymarc and spacing on measured soil chemical properties except for soil pH. The correlation analysis between nutrients was positive, highly significant ($p < 0.01$), and varied from moderate to strong ($0.4 < r < 0.7$ and $r > 0.7$) except pH. The treatment with the highest bush bean yield was P2S1 with 3.03 t ha⁻¹ and therefore it can be recommended to bush bean farmers of the volcanic highland region.

Key words: Bush beans, pymarc rates, inter- row spacing and soil chemical parameters**1.0 Introduction**

Agriculture is reckoned as a fundamental industry. It supplies food for consumption and raw materials for agro-based industries (Boehlje & Bröring, 2011). Unfortunately, countries in the sub-Saharan part of Africa are meeting the global challenge of food production capacity as result of exponential increase in population coupled with the decline in fertility of arable lands (Blessing, 2016; Sánchez, 2010). Therefore, a great number of African countries are unable to

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link agricultural production with rapid increase of population to solve food scarcity problem (Boehlje & Bröring, 2011; Rakotoarisoa et al., 2011 and Worse than that, around 65% of cultivable land in Africa is degraded (Gardner et al., 2015; Vlek et al., 2010). Regardless of manifold ways, means, and time allocated to solve that hindrance, degradation of soil fertility persists. As a result, soil degradation is a significant challenge for food security in Africa (Masila, 2016; Tilahun, 2018).

Furthermore, the decrease in soil's productivity ability came from soil's long-term over-exploitation for crop production without adequate nutrient replenishment and protection, leading to soil degradation and chronic plant nutrient deficiency (Chemining'wa et al., 2011). Thus, improving soil fertility is one of the most important actions taken to increase crop yield. Combination of mineral and organic fertilizers and adoption of other agronomic practices could be practiced to supply consumed plant nutrients (Bayu et al., 2006; Biramo, 2018; Nyongesa et al., 2010). Concerning the land resource limitations and exponential population growth, the Rwanda government, through its Ministry of Agriculture and animal resources, instituted in September 2007, the Crop Intensification Program (CIP) to tackle the food security problem (Musabanganji et al., 2016; Nahayo et al., 2017). CIP intended to increase crop production on small area in regard of selected promising crops: beans, rice, cassava, wheat, soybean, Irish potato and maize using improved inputs (Miklyaev et al., 2020). This was in line with Vision 2020 and Vision 2050, where one of their pillars is to ensure food security and market-oriented agriculture for both men and women (Kaberuka, 2000; Popa & Beţco, 2020). To achieve this program, the government of Rwanda has initiated subsidy vouchers to enhance the use of mineral fertilizers and other agricultural inputs for small-holder farmers as one of the CIP pillars (Ndushabandi et al., 2018). As an ultimate result of CIP, mineral fertilizer use has increased from 4 kg/Ha per year in 2006 to 31 kg/Ha and even 89 kg/Ha for wealthier farmers per year in 2020 (Kim et al., 2022). It is of paramount importance to note that mineral amendments easily leach from the root zone and thus become inaccessible to crops. Nevertheless, this hindrance can be reduced by the application of organic inputs since they assist in retaining leachable mineral nutrients and supplying them to plants in due time (Ogutu, 2013).

Additionally, Berry & Olson (2003), Schulz et al. (2003), and Nyongesa et al. (2009) stated that "there are not enough organic fertilizers" in Rwanda and Africa at large. Pymarc (pyrethrum marc) is an organic by-product of pyrethrin extraction from the shoots and flowers of pyrethrum (*Tanacetum Cinerarifolium*) that can be used to alleviate this problem (Nyongesa et al., 2009, 2010). Pymarc is less used in Rwanda for bush bean farming, and there is little data about its application rates as an organic fertilizer. One ton of dried pyrethrum flowers produces about 970 kg of pyrethrum marc after extracting pyrethrins (Nyongesa et al., 2009). Despite all the CIP achievements, an upgraded seasonal survey indicated that the bush bean means the yield is still low in Rwanda with 0.7 t ha⁻¹ compared to potential yields, which vary from 1.5 t ha⁻¹ to 2.5 t ha⁻¹ (NISR, 2020). Furthermore, no sufficient data is available in terms of the effect of different bush bean spacings on the chemical properties and yield of common beans (Njoka et al., 2005). With ample consideration to these stumbling blocks, this

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study was thus undertaken to determine pyrethrum marc and intra-row-spacing effects on selected soil parameters and bush bean (*Phaseolus Vulgaris L*) yield on andisol under rainfed conditions. Specific goals included: i) determining the impact of pymarc rates and recommended dose of NPK 17-17-17 on chemical parameters and bush bean yield; ii) determining the impact of bush bean spacing on selected soil chemical parameters and bush bean yield; iii) determining the interaction effect of pyrethrum levels in combination with recommended dose of NPK 17-17-17 and spacing levels on soil chemical attributes and bush bean yield.

2.0 Methodology

2.1 Study area

The study was conducted on a field of farmers located in Musanze District in the Northern Province of Rwanda, and its geographical coordinates are: Longitude: 29°39'36.1" E with Latitude: 1°29'00.7" S and an altitude of 1875 m above sea level. The site received an average annual rainfall ranging from 1400 mm to 1800 mm and had a mean temperature of 20°C. The total rainfall received on the site during the cropping period was 774.6 mm, with an effective rainfall of 519.68 mm. The soil type of the site was volcanic and its taxonomy was andosol according to FAO classification (FAO, 2014).

2.2 Design, treatments and field management

The experiment was factorial with two factors; plant spacing levels S1(40cm x 15 cm); S2(40 cm x 20 cm) and S3(40 cm x 30 cm) and pyrethrum marc application rates P0(No fertilizer added); P1(0 t ha⁻¹ of pymarc + 250 kg ha⁻¹ of NPK 17-17-17); P2(10 t ha⁻¹ of pymarc + 250 kg ha⁻¹ of NPK 17-17-17); P3(15 t ha⁻¹ of pymarc + 250 kg ha⁻¹ of NPK 17-17-17); and P4(20 t ha⁻¹ of pymarc + 250 kg ha⁻¹ of NPK 17-17-17). The design was a randomized complete block (RCBD) with four replications. The spacing between blocks and experimental plots was 1 m and 0.5 m sequentially. Size of each plot was 1.5 m x 1.8 cm. The thinning was done 4 weeks after sowing and NPK 17-17-17 was applied two times; one at 3 weeks after sowing and a second one at 6 weeks after sowing, while pymarc was incorporated into the soil at sowing. Weeding was done twice throughout the season and control of pests and diseases was done by spraying SAFARI 80WP (Mancozeb 80 %) and ROKET 44EC (Profenols 40 % + Cypermethrin 4% EC) in five rounds.

2.3 Data collected

Soil chemical attributes during this study were: pH, Exchangeable K (Exch. K), Organic C (OC), Available P (Av. P), Total N (TN), and exchangeable bases like Calcium and Magnesium (Exch. Ca and Mg). Before sowing, during the flowering stage (65 days after sowing), and at harvest (115 days after sowing), data on chemical parameters were collected. The bush bean yield was determined by weighing threshed beans from each plot.

2.4 Soil samples collection and analysis of both soil pymarc samples

Soil samples were collected at a depth of 0-20 cm by the diagonal method within a field experiment using a soil auger before pymarc application seeds sowing. Soil samples were

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collected, mixed to obtain a homogenous composite sample, air dried, and passed through 0.5 mm and 2.0 mm sieves. Composite soil samples were assessed for pH, organic C, available P, exchangeable Ca, total N, exchangeable K, and Mg, texture, and bulk density.

Soil and pymarc pH were measured by the glass electrode method (Jackson, 1958) with a 1:2.5 soil/pymarc-water ratio. Organic C was found with the help of the loss of ignition method (Schulte & Hopkins, 1996). Mineralization method was used to find out the total N (Chapman & Parker, 1961). Determination of available phosphorus was achieved by the Mehlich-3 method (Mehlich, 1984). Exchangeable Potassium, Calcium and Magnesium were found out by Versenate (EDTA) titration methods (Blake & Hartge, 1986). Soil texture was determined by using the hydrometer method (Bouyoucos, 1962), and bulk density was determined by using the core method (Blake & Hartge, 1986).

The organic fertilizer used for this study was pymarc and originated from HORIZON SOPYRWA, which is a pyrethrum processing factory located in Musanze District. Well-decomposed pymarc was applied to the soil three days before sowing to reach soil temperature.

2.5 Analysis of data

Collected data were statistically analyzed by GenStat 14th edition for ANOVA while means separation was done by Fisher's protected LSD at $p < 0.05$. Correlation analysis was carried out by Stata PM 13 with Pearson correlation method at $p < 0.05$.

3.0 Results and discussions

3.1. Initial characteristics of site soil and pymarc

The soil texture analysis before sowing results were 80.1 % sand, 0.1 % silt and 19.8 % clay and the texture was classified as fine sandy loam soil (Table 1). This texture is favored by bush beans but maximum yield is attained in well-drained sandy loam soils (Leap et al. 2017). Pre-sowing soil pH was 5.59 (moderately acidic) (Horneck et al., 2011). According to Duarah et al. (2011), the optimum pH ranges for bush beans are from 5.5 to 6.8. In this study, bulk density was 1.16 g cm⁻³, and organic carbon content was 4.2% (Okalebo et al., 2002).

Table 1 Pre-sowing experimental site soil and pyrethrum marc characteristics

Parameter	Experimental site soil (Initial Characteristics)	Pyrethrum marc (Organic Fertilizer)
Bulk density	1.16 g/cm ³	
Texture		
- Sand	80.1 %	
- Silt	0.1 %	
- Clay	19.8 %	
Soil textural class	Fine Sandy loam soil	
pH _{water}	5.59	7.10
Organic C	4.2 %	38.97 %
Total N	0.138 %	0.140 %
Available P	49.4 ppm	145.20 ppm
Exchangeable K	43.2 mg dm ⁻³	65.4 mg dm ⁻³
Exchangeable Ca	10.3 Cmol Kg ⁻¹	39.0 Cmol Kg ⁻¹
Exchangeable Mg	2.4 Cmol Kg ⁻¹	36.0 Cmol Kg ⁻¹

At the pre-sowing time, total nitrogen was moderate at 0.130 % (Okalebo et al., 2002) and was moderately sufficient for bean production by considering nitrogen fixation (nodules) and organic matter decomposition (Hergert & Schild, 2013). Available Phosphorus was moderate (49.40 ppm), (Kalisa & Nshimyumukiza, 2007) and insufficient for beans that require, greater than 50 ppm of available P, (Heinrich et al., 2016). Exchangeable Potassium was rated low with 43.2 mg dm⁻³ (Ransom, 2004) The soil's initial characteristics in light of exchangeable bases, Ca was high (10.3 Cmol Kg⁻¹), (Kalisa & Nshimyumukiza, 2007) and sufficient for high bush bean yield, (Heinrich et al., 2016), while Mg concentrations were low (2.4 Cmol Kg⁻¹), (Kalisa & Nshimyumukiza, 2007) and is within the range of favourable bush bean production, (Guo et al., 2016). The organic fertilizer used was pyrethrum marc (pymarc), and its characteristics are summarized in table 1.

3.2 Chemical parameters and bush bean yield

3.2.1 Effect of pymarc on chemical parameters and bush bean yield

3.2.1.1 Effect of pymarc on pH and total Carbon

This study pointed out that a highly significant difference ($p < 0.01$) was among five application rates of pymarc in terms of pH and TOC (Table 2). At the flowering stage, higher pH (5.76) was recorded in P3 (15 t ha⁻¹ of pymarc + 250 Kg ha⁻¹ of NPK 17-17-17) and P4 (20 t ha⁻¹ of pymarc + 250 Kg ha⁻¹ of NPK 17-17-17) than in P0, which had no fertilizer application with the least pH (5.57), which followed P1 (250 Kg ha⁻¹ of NPK 17-17-17) with pH of 5.59 ($p < 0.05$). At harvesting time, P3 and P4 exhibited greater changes ($p < 0.01$) in soil pH, 5.82 and 5.80, respectively, than P0 and P1 ($p < 0.01$).

The increase in soil pH from flowering stage to harvesting time could be adjusted to the gradual break up of pymarc into assimilable nutrients and resulted in a liming effect because the pH of pymarc was a bit higher (7.1) than that of the soil before sowing (Naramabuye et al., 2008; Odongo et al., 2011). The treatments that received both pyrethrum marc and NPK 17-17-17 had tremendous increases in pH values at both stages as compared to the initial pH, and this concurs with the findings of Yaduvanshi (2003), who stated that the organic matter from organic amendment engulfs H⁺ ions and consequently pH increases.

The treatments P0 and P1, which received neither pymarc nor NPK alone, had low pH and this could explain the consequences of soil OM decrease, which in turn decreases the H⁺ absorbing sites and, consequently, H⁺ ions are hugely released into the soil solution, thus the decrease in soil pH or increase in soil acidity (Singh, 2018).

In light of total Carbon(TOC), P2 (10 t ha⁻¹ of pymarc + 250 kg ha⁻¹ of NPK 17-17-17) had a higher TOC of 5.12% than P0 and P1, which had the lowest TOC ($p < 0.01$) of 4.16 and 4.48% sequentially at flowering stage. At harvesting, the treatments P3 and P4 had tremendous amounts of TOC of 5.52 and 5.31 %, respectively, as compared to P0 and P1. Organic carbon increased with an increase in pymarc application rates at harvesting time as compared to P0, which had no fertilizer application, and P1, which had received only 250 Kg ha⁻¹ of NPK ($P < 0.01$) (Antil et al., 2001). The boost in OC was because pymarc is very rich in OC (0.389 %)

and its application to the soil led to the formation of stable OM, as previously proven by other studies by Bhattacharyya et al. (2007) and Lal (2004).

3.2.1.2 Effect of pymarc on total Nitrogen and available Phosphorus

In terms of total Nitrogen, P4 had the highest record of 0.28% compared to P0 with low quantity of 0.12% at flowering, while at post-harvesting time, it slightly increased and still P4 had a high TN (0.30%) compared to P0 which had a low TN (0.11%) ($p < 0.01$).

The highest amount of available P was recorded in P4 at both stages, with 59.07 ppm at blooming time and 56.70 ppm at harvesting time. The lowest available P was recorded in P1 with 51.07 ppm at flowering and 49.17 ppm at a post-harvesting time for NPK-based treatments (Table 2) ($p < 0.01$).

With respect to flowering and harvesting stages, available P has decreased during the flowering and harvesting stages, most likely because phosphorus was tightly bound to soil particles in sandy soil and thus moderately immobile (Ige et al., 2005). The synergistic effects of using organic and mineral inputs together resulted in more nitrogen and available phosphorus (Ge et al., 2018; Huang et al., 2007; Hutchinson et al., 2006; Khuram et al., 2013; Shisanya et al., 2009).

3.2.1.3 Effect of pymarc on exchangeable bases K, Ca, Mg and bush bean yield

The highest quantity of exchangeable potassium of 79.68 mg dm⁻³ was in P4, whereas the lowest K was in P0 (41.10 mg dm⁻³) at the blooming stage. After harvesting, the P4 treatment had the highest av. K (81.30 mg dm⁻³) compared to P0, which had the lowest exchangeable K (41.10 mg dm⁻³) (Table 2).

Exchangeable base calcium was great in P4 with 13.68 Cmol Kg⁻¹ at flowering as opposed to P0 with 9.97 Cmol Kg⁻¹ and P1 possessed 11.62 Cmol Kg⁻¹ of exchangeable base calcium in treatments with the recommended dose of NPK 17-17-17. Exchangeable Ca was high in P4 and low in P0 with values of 12.61 and 7.87 Cmol Kg⁻¹ respectively at harvesting time (Table 2).

P4 had the most Mg in the soil solution with 5.33 Cmol Kg⁻¹, while P0 had 2.23 Cmol Kg⁻¹ of exc. Mg is in full bloom. P4 had the highest exchangeable Mg (5.00 Cmol Kg⁻¹) and P0 had the lowest exchangeable Mg (2.18 Cmol Kg⁻¹) at harvest, but P1 also had low Mg when NPK-based treatments were used (Table 2).

Exchangeable cations like K⁺, Ca²⁺, and Mg²⁺ were more likely found in treatment with a high application rate of pyrethrum marc P4 (20 t ha⁻¹ of pymarc and 250 kg ha⁻¹ of NPK) ($p < 0.01$). This is because pyrethrum marc has a high content of those cations when compared to the initial soil conditions, and organic fertilizers are ultimately the main sources of exchangeable cations (Ogundijo et al., 2015). The increase in K⁺, Ca²⁺, and Mg²⁺ was directly linked to the decomposition of pymarc which swiftly increased their detachment and fixation on soil colloids

(Ahmady et al., 2020).

The yield varied at different pymarc rates whereby P2 and P3 had same effect with 2.47 and 2.36 t ha⁻¹ as opposed to P0 with the lowest bush bean yield of 1.46 t ha⁻¹ ($p < 0.01$). Reasonable fertilization of mineral and organic amendments resulted in higher yields. The treatment that had high pymarc didn't exhibit high yield, probably due to marginal or light (hidden) toxicity from an excess supply of nutrients (Shand, 2007).

3.2.2 Influence of bush bean spacing on selected soil chemical parameters and yield

3.2.2.1 Effect of spacing on pH

No significant difference was observed between three treatments of plant spacing (S1 (40cm x 15cm), S2 (40cm x 20cm) and S3 (40cm x 30cm)) at flowering stage and harvesting time ($p < 0.05$). To a great extent, soil pH fluctuation is influenced by: type of vegetation, management of land and its use, climate, content of mineral substances, soil granulometric type and inputs amendments (Zhang et al., 2019). Similar results were observed by Hadiayompamungkas et al. (2019) and Kumar et al. (2014).

3.2.2.2 Influence of bush bean spacing on organic C, total N and available P

Plant spacing had highly significant differences in concentrations of OC, TN, and av. P with $p < 0.01$ at flowering time, while OC and av. P showed highly significant differences at harvesting time. At both flowering and harvesting times, the plant spacing S3 (40cm x 30 cm) contained the highest amounts of organic C with 5.0 % and 4.85 % sequentially, as alluded to by S1 (40 cm x 15 cm), which had the least OC of 4.43 % and 4.66 % at blooming and harvesting stages respectively.

Additionally, the plant spacing treatment which held tremendous record of total N at flowering period was S3 with 0.21 %. The lowest amount of total N at flowering of 0.20 % was recorded in S1 and S2 while at harvesting no significant difference was remarked among spacing treatments. Highest content in av. P was recognized in S3 at both stages, for at blooming it was 57.70 ppm and 55.15 ppm at harvesting. The lowest av. P was recorded in S1 with 52.49 ppm at flowering and 50.90 ppm at harvesting period.

The findings indicated that small plant spacing increased the number of plants per unit area and it resulted in high exploitation of plant nutrients (organic C, total N, and available P) (Duan et al., 2019).

3.2.2.3 Effect of spacing on exchangeable K, Ca, Mg and bush bean yield

The highly significant difference was observed in spacing treatments in terms of exchangeable cations and yield ($p < 0.01$). With the same token, S3 still had higher quantities of exch. K at flowering was 62.4 mg dm⁻³ and 60.94 mg dm⁻³ at post-harvest time. The lowest quantity of available K was noted in S1 with 57.53 and 55.74 mg dm⁻³ at flowering and harvesting periods sequentially.

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The remarkable rates of exchangeable Ca were found in S3, with 13.2 and 11.0 Cmol Kg⁻¹ at blooming and post-harvest times accordingly. The least values of exch. Ca of 11.39 and 9.76 Cmol Kg⁻¹ were recorded at flowering and harvesting times sequentially.

Table 2: influence of pymarc and spacing on chemical properties at flowering and harvesting time

Pymarc treatments	At flowering stage							At harvesting time							
	pH	OC (%)	TN (%)	Av. P (ppm)	Av. K (mg dm ⁻³)	Ca (Cmol Kg ⁻¹)	Mg (Cmol Kg ⁻¹)	pH	OC (%)	TN (%)	Av. P (ppm)	Av. K (mg dm ⁻³)	Ca (Cmol Kg ⁻¹)	Mg (Cmol Kg ⁻¹)	Yield (t ha ⁻¹)
P0	5.57 ^c	4.16 ^a	0.12 ^a	49.40 ^d	42.22 ^a	9.97 ^e	2.23 ^a	5.45 ^c	3.91 ^a	0.11 ^a	48.07 ^d	41.10 ^a	7.87 ^e	2.18 ^d	1.46 ^c
P1	5.59 ^{bc}	4.48 ^d	0.14 ^d	51.07 ^c	46.13 ^d	11.62 ^c	2.66 ^d	5.69 ^b	4.24 ^d	0.12 ^d	49.17 ^c	43.21 ^d	8.30 ^f	2.68 ^e	2.07 ^b
P2	5.71 ^{ab}	5.12 ^a	0.22 ^c	56.39 ^b	60.02 ^c	13.50 ^a	3.68 ^c	5.77 ^{ab}	4.7 ^c	0.20 ^c	54.07 ^b	56.82 ^c	11.78 ^b	2.77 ^c	2.47 ^a
P3	5.76 ^a	4.93 ^b	0.25 ^b	59.23 ^a	71.18 ^b	12.73 ^b	4.91 ^b	5.82 ^a	5.52 ^a	0.26 ^b	56.57 ^a	69.20 ^b	11.45 ^b	3.32 ^b	2.36 ^a
P4	5.75 ^a	4.80 ^c	0.28 ^a	59.07 ^a	79.68 ^a	13.68 ^a	5.33 ^a	5.80 ^a	5.30 ^b	0.30 ^a	56.70 ^a	81.30 ^a	12.61 ^a	5.00 ^a	2.07 ^b
p-Value	0.008	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Spacing treatments															
S1	5.70 ^a	4.43 ^c	0.20 ^b	52.49 ^c	57.53 ^c	11.39 ^c	3.35 ^b	5.67 ^a	4.66 ^c	0.19 ^a	50.90 ^c	55.74 ^c	9.76 ^c	2.76 ^c	2.38 ^a
S2	5.67 ^a	4.63 ^b	0.20 ^b	54.90 ^b	59.59 ^b	12.34 ^b	3.88 ^a	5.70 ^a	4.71 ^b	0.20 ^a	52.70 ^b	58.31 ^b	10.41 ^b	3.24 ^b	2.00 ^b
S3	5.67 ^a	5.0 ^a	0.21 ^a	57.70 ^a	62.4 ^a	13.20 ^a	4.1 ^a	5.77 ^a	4.85 ^a	0.20 ^a	55.15 ^a	60.94 ^a	11.0 ^a	3.6 ^a	1.88 ^b
p-Value	0.704	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.072	< 0.001	0.073	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
CV (%)	2.7	1.5	3.7	2.6	2.1	6.8	8.4	2.4	0.9	5.2	2	2.1	5.4	6.3	14.3

Values followed by the same letter in superscript in each column do not differ significantly at p<0.05, Av. P: Available phosphorus, OC: organic carbon, Av. K: Available potassium, TN: Total nitrogen

Considering the amount of exch. Mg, the highest quantities were noted in S3, and values of 4.1 and 3.6 Cmol Kg⁻¹ were recorded at both stages sequentially. In addition to that, S2 exerted a similar effect to S3 at flowering, whilst the lowest amounts of exch. Mg was observed in S1, with 3.35 and 2.76 Cmol Kg⁻¹ at both stages, respectively.

All in all, the increase in spacing of bean plants increased OC, av. P, TN, and exchangeable cations K⁺, Ca²⁺, and Mg²⁺ as well (Table 2). Due to bush bean root extraction, these nutrients were less at harvesting time, and plants needed 40 % of all the required nutrients for their whole cycle at the maturity stage (Jia et al., 2018).

For bush bean yield, a highly significant difference was found among three plant spacings (p<0.01). Furthermore, the plant spacing treatment S1 had the highest yield of 2.88 t ha⁻¹ as opposed to S3, which gave 1.88 t ha⁻¹(Table 2). The trend behind plant spacing and yield was that the wider the plant spacing, the lesser the bush bean yield and vice versa. These results conform with the findings of Muchira et al. (2018) and OECD (2016), who reported that plant spacing S1(40 cm x 15 cm) resulted in the highest economic yield in bush bean farming.

3.2.3 Interaction effect of pyrethrum marc and spacing on soil chemical properties

3.2.3.1 Interaction effect of pymarc and spacing on soil pH, organic C, total N and av. P

There was no interaction effect between pymarc and bean spacing regarding pH ($p < 0.05$) at flowering and harvesting stages because it is not mentioned among factors that affect the variability of pH (Hadiyompamungkas et al., 2019).

Additionally, at either flowering or harvesting time, there was a highly significant difference among treatments in terms of the interaction effect of pymarc and plant spacing on organic C. Therefore, during the flowering period, P3S3, P4S3, and P2S3 had the same interaction effect with marvelous amounts of 5.45, 5.44, and 5.40 % of OC, respectively, contrary to the lowest organic C found in POS1 of 3.97 %. In the same manner, at harvesting, P4S3 and P3S1 possessed 5.71 and 5.66 % of OC, respectively, as opposed to POS1, with the lowest amount of OC (3.80 %) (Table 3)

Considering total N, there was an interaction effect ($p < 0.01$), and it was noted that at both stages, P4S3 contained the greatest quantities, 0.31 and 0.30 percent sequentially, as opposed to POS1, with the least amounts of total N of 0.12 and 0.09 percent, respectively. Taking into account the amount of av. P, the treatments P3S3 and P4S3 exerted the same effect in light of pymarc and spacing interaction effects ($p < 0.01$), at flowering with 63.90 and 64.90 ppm and harvesting with 60.9 and 59.9 ppm separately. Oppositely, P0 with all three spacings manifested low content of av. P at both stages (Table 3).

The significant differences in interaction effects are due to different supplies of examined nutrients from various rates of pyrethrum marc and NPK 17-17-17 for different spacing. The greater pymarc application rate with large plant spacing engendered higher amounts of nutrients (OC, TN, and av. P) because there was less depletion of nutrients from plant roots and therefore nutrients left in the soil unused (leftover) (Nair, 2019; Umeugokwe et al., 2021). Moreover, Shand (2007) and Salifu & Timmer (2003) expounded different zones of concentration of plant nutrients in the soil from insufficiency to toxic levels whereby they underlined light toxicity, which is instigated by plant nutrient replenishment in slight excess, which brings about a discrete baneful impact and thus, at this stage, no tangible symptoms may be noticeable.

3.2.3.2 Interaction effect of pyrethrum marc and spacing on bush bean yield and exchangeable K, Ca and Mg

A perusal of exch. K, Ca and Mg results (Table 3) revealed that an interaction effect of pymarc and spacing was only highly significant ($p < 0.01$) for exch. K and significant ($p < 0.05$) for exch. Mg at flowering. At harvesting there was highly significant ($p < 0.01$) for exch. K and Mg while it was significant ($p < 0.05$) for Ca. In regard of exchangeable potassium, at blooming and harvesting periods, P4S3 contained 83.2 and 85.6 Cmol Kg^{-1} separately compared to POS1 and POS2 with mediocre amount of exch. K.

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Resting on exchangeable Ca, results presented in table 3 showed that only at harvesting time, the interaction effect was present with the highest amount of Ca (13.9 Cmol Kg⁻¹) in P4S3 and the lowest exch. Ca in P0 and P1 combined with the three spacings used in this study. Furthermore, P4S3 contained the highest exch. Mg has a blooming concentration of 5.90 Cmol/Kg and a post-harvesting concentration of 5.5 Cmol/Kg-1, but the least amount of exch. Mg was recorded at flowering in POS1 and POS2, while at harvesting it was found in POS1 (Table 3).

In general, there were fewer quantities of these cations at harvesting than at flowering, which was because plants require more nutrients at maturity, around 60% of all needed nutrients than at other stages (Jia et al., 2018). All in all, the narrower spacing (S1) with no application of fertilizers (P0) led to the stronger mining of exch. K, Ca, and Mg than the wider spacing (S3) with the highest fertilizer application rate (P4). These results are in line with the findings of Gezahegn (2019).

The interaction effect of plant spacing and pymarc was significant ($p < 0.05$) on bush bean yield and P2S1 (10t ha⁻¹ of pymarc + 250 kg ha⁻¹ of NPK with 40 cm x 15 cm) had the highest yield with 3.03 t/ha as compared to POS3 (No fertilizer with 40 cm x 30 cm), which had the lowest yield of 1.30 t/ha. Among NPK-based treatments, P1S3 (No pymarc + 250 kg/ha of NPK) yielded 1.89 t/ha.

These results were an eye witness to the ultimate results which await for either using no fertilizer or mineral fertilizer only or the conjunctive use of organic and inorganic fertilizers. Most yields have been reached only when both fertilizers are widely used (Ayeni & Adetunji, 2010; Eifediyi & Remison, 2010). On the other hand, P4S1 failed to give a high bush bean yield as the treatment with a high pymarc rate, probably on account that excessive nutrient replenishment led to hidden toxicity (Salifu & Timmer, 2003; Shand, 2007).

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Table 3: interaction effect of pymarc and intra-row-spacing on selected chemical properties at flowering stage and post-harvest time

Treatments	At flowering							After harvesting time							Yield (t ha ⁻¹)
	pH	OC (%)	TN (%)	Av. P (ppm)	Av. K (mg dm ⁻³)	Ca (Cmol Kg ⁻¹)	Mg (Cmol Kg ⁻¹)	pH	OC (%)	TN (%)	Av. K (mg dm ⁻³)	Mg (Cmol Kg ⁻¹)	Av. P (ppm)	Ca (Cmol Kg ⁻¹)	
P0xS1	5.55 ^a	3.97 ^b	0.12 ^j	48.90 ⁱ	41.5 ^a	8.7 ^d	2.15 ^h	5.37 ^a	3.80 ⁱ	0.09 ^l	39.8 ^b	1.8 ^g	46.9 ^f	7.6 ^e	1.77 ^a
P0xS2	5.58 ^a	4.21 ^a	0.12 ^j	49.40 ^{hi}	42.3 ^b	9.5 ^{cd}	2.23 ^h	5.45 ^a	3.91 ^b	0.11 ⁱ	41.1 ^b	2.2 ^f	47.4 ^e	7.9 ^{de}	1.32 ^f
P0xS3	5.58 ^a	4.29 ^{ab}	0.13 ⁱ	49.90 ^{hi}	42.8 ^b	11.7 ^{abcd}	2.35 ^{gh}	5.54 ^a	4.02 ^b	0.12 ^{ij}	42.4 ^b	2.6 ^e	49.9 ^d	8.2 ^{de}	1.30 ^f
P1xS1	5.63 ^a	4.36 ^a	0.13 ^{ij}	49.40 ^{hi}	44.4 ⁱ	10.8 ^{abcd}	2.30 ^{gh}	5.65 ^a	4.15 ^b	0.11 ⁱ	41.1 ^b	2.3 ^f	48.4 ^{de}	8.0 ^{de}	2.15 ^{bcde}
P1xS2	5.59 ^a	4.53 ^a	0.14 ^h	51.40 ^{gh}	46.2 ⁱ	11.8 ^{abcd}	2.75 ^{fe}	5.69 ^a	4.27 ^b	0.13 ^{ij}	43.0 ⁱ	2.8 ^e	49.4 ^d	8.3 ^{de}	2.16 ^{bcde}
P1xS3	5.56 ^a	4.56 ^a	0.15 ^h	52.40 ^{gh}	47.7 ⁱ	12.2 ^{abcd}	2.95 ^f	5.72 ^a	4.31 ^b	0.13 ^{ij}	45.5 ^b	2.9 ^e	49.7 ^d	8.6 ^d	1.89 ^{de}
P2xS1	5.71 ^a	4.86 ^a	0.21 ^f	54.87 ^{de}	57.7 ^h	12.8 ^{ab}	3.15 ^f	5.69 ^a	4.63 ^{ab}	0.19 ^h	53.6 ^e	2.1 ^f	52.9 ^e	11.1 ^{de}	3.03 ^a
P2xS2	5.73 ^a	5.09 ^b	0.23 ^e	56.90 ^{cd}	57.8 ^h	13.6 ^{ab}	3.95 ^e	5.77 ^a	4.62 ^{ab}	0.20 ^h	58.0 ^f	2.8 ^e	53.9 ^{de}	11.8 ^{cd}	2.38 ^{bcd}
P2xS3	5.69 ^a	5.40 ^b	0.23 ^e	57.40 ^{bc}	64.5 ^e	14.1 ^a	3.95 ^e	5.87 ^a	4.87 ^f	0.22 ^g	58.8 ^f	3.4 ^d	55.4 ^d	12.4 ^b	2.00 ^{cd}
P3xS1	5.81 ^a	4.63 ^{de}	0.29 ^b	55.40 ^{bc}	67.9 ^f	12.1 ^{abc}	4.60 ^d	5.82 ^a	5.66 ^g	0.30 ^{gh}	66.9 ^g	3.2 ^d	53.4 ^d	10.8 ^a	2.61 ^{ab}
P3xS2	5.72 ^a	4.72 ^d	0.24 ^c	58.40 ^b	71.8 ^g	12.9 ^{ab}	4.90 ^{cd}	5.78 ^a	5.57 ^b	0.26 ^d	68.4 ^g	3.3 ^d	55.4 ^{cd}	11.5 ^{cd}	1.97 ^{de}
P3xS3	5.75 ^a	5.45 ^b	0.24 ^c	63.90 ^a	73.8 ^g	13.2 ^{ab}	5.23 ^{bc}	5.86 ^a	5.34 ^c	0.24 ^c	72.3 ^d	3.5 ^d	60.9 ^a	12.0 ^{bc}	2.49 ^{bc}
P4xS1	5.81 ^a	4.34 ^d	0.25 ^d	53.90 ^{cd}	76.0 ^g	12.5 ^{abc}	4.53 ^d	5.83 ^a	5.05 ^c	0.28 ^c	77.3 ^c	4.4 ^c	52.9 ^e	11.3 ^{cd}	2.32 ^{bcd}
P4xS2	5.71 ^a	4.62 ^{de}	0.28 ^b	58.40 ^b	79.8 ^h	13.9 ^{ab}	5.6 ^{cd}	5.84 ^a	5.16 ^d	0.29 ^{bc}	81.0 ^b	5.1 ^b	57.4 ^b	12.6 ^b	2.17 ^{bcde}
P4xS3	5.74 ^a	5.44 ^b	0.31 ^a	64.90 ^a	83.2 ^a	14.6 ^a	5.90 ^a	5.87 ^a	5.71 ^a	0.30 ^a	85.6 ^a	5.5 ^a	59.9 ^a	13.9 ^a	1.72 ^{de}
p-Value	0.993	< 0.001	< 0.001	< 0.001	< 0.001	0.303	0.052	0.959	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.033	0.016
CV (%)	2.7	1.5	3.7	2.6	2.1	6.8	8.4	2.4	0.9	5.2	2.1	6.3	2	5.4	14.3

In every column, values with the same superscript letter do not differ significantly at $p < 0.05$; Av. K: Available potassium; TN: Total nitrogen, Av. P: Available phosphorus, OC: Organic carbon

Plant nutrients are to be applied by keeping in mind 4Rs stewardship rule (Right amount, Right source, Right time and Right placement of fertilizers), (Bruulsema, 2018).

3.2.4 Correlation analysis among selected parameters

3.2.4.1 Correlation analysis at flowering stage

At flowering stage, correlation analysis results (Table 4) indicated that soil pH had a weak ($r < 0.4$) with OC, av. P, and exch. Ca while it had a positive, highly significant relationship ($p < 0.01$) with total N, exchangeable cations K^+ , and Mg^{2+} at flowering stage. Organic carbon (OC) had a strong relationship ($r > 0.7$) with av. P and exch. Ca, which was highly significant and positive at the flowering stage.

Total N possessed a positive, strong and highly significant correlation with av. P, av. K and exch. Mg, and it was moderate for exch. Ca at the flowering stage. The relationship between av. P with Av. K, exch. Ca, and Mg was highly significant positive and varied from moderate to strong at both stages. The same correlation was observed between Av.K and exchangeable cations Ca and Mg. Eventually, the correlation between Ca and Mg was positive, highly significant ($p < 0.01$) and moderate ($0.4 < r < 0.7$).

The application of pyrethrum marc engendered the liming effect (increase in pH), and this led to the increase of organic C, total N, available P, available K, exchangeable Ca, and Mg. Usually, soil pH controls the availability and solubility of plant nutrients. Very acidic soil ($pH < 4.5$) and very alkaline soil ($pH > 8.3$) impact on micro-organisms' labor and, generally, many plant

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nutriments become inaccessible (Shabala, 2017). In very acidic soils, phosphorus, exch. Ca, and Mg lean to bond with Al³⁺ and iron that are predominant and become unattainable to crops. Furthermore, phosphorus becomes unavailable to plants by binding together with calcium to make a Ca-P bond in very alkaline soils (Wilkinson, 2000). The positive correlation of N and other plant nutrients resulted in their high uptake and resulted in a high yield (Fageria, 2001).

3.2.4.2 Correlation analysis results at harvesting time

At harvesting time, not many changes happen. Nevertheless, the correlation between pH and all the parameters except yield was moderate (0.4<r<0.7), positive and highly significant (p<0.01). Additionally, the relationship between organic carbon and TN, av. P, av. K, as well as exch.Ca, became strong, positive, and still highly significant, and yet, it was moderate with exch. Mg. While the correlation between N and other nutrients (available P, exchangeable K, Ca, and Mg) was strong and significantly positive with available P, exchangeable K, Ca and Mg (Table 4).

The correlation between av. P and cations (K⁺, Ca²⁺, and Mg²⁺) fluctuated from moderate to strong, highly significant, and positive. An identical relationship was noted between exchangeable K and the rest of the cations (Ca²⁺ and Mg²⁺). Furthermore, the relationship between Ca and Mg was moderate and highly significant at both stages. The bush bean yield had a weak, positive, and significant correlation with all selected parameters except pH. Even though the relationship between yield and other chemical attributes was weak, the yield increased with the increase of nutrients up to the application of 10 t ha⁻¹ of organic fertilizer (Bucagu et al., 2017; Kibunja et al., 2012). The positive correlation between parameters indicated their inter-dependency (Duan et al., 2019; Nwokwu, 2020).

Table 4: Correlation analyses between chemical parameters themselves and between them and yield

Parameters	At flowering stage							At harvesting time							
	pH	OC	TN	Av. P	Av.K	Exch. Ca	Exch. Mg	PH	OC	TN	Av. P	Av. K	Exch. Ca	Exch. Mg	Yield
pH	r 1.00							1.00							
OC	r 0.29	1.00						0.64	1.00						
	p 0.03							0.00							
TN	r 0.46	0.59	1.00					0.64	0.91	1.00					
	p 0.00	0.00						0.00	0.00						
Av. P	r 0.35	0.81	0.75	1.00				0.64	0.78	0.80	1.00				
	p 0.01	0.00	0.00					0.00	0.00	0.00					
Av. K	r 0.44	0.61	0.90	0.85	1.00			0.61	0.88	0.95	0.84	1.00			
	p 0.00	0.00	0.00	0.00				0.00	0.00	0.00	0.00				
Exch. Ca	r 0.38	0.72	0.66	0.76	0.72	1.00		0.58	0.82	0.82	0.79	0.86	1.00		
	p 0.00	0.00	0.00	0.00	0.00			0.00	0.00	0.00	0.00	0.00			
Exch. Mg	r 0.45	0.64	0.88	0.81	0.92	0.64	1.00	0.59	0.67	0.76	0.71	0.82	0.62	1.00	
	p 0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00		
Yield	r -	-	-	-	-	-	-	0.43	0.31	0.38	0.30	0.27	0.29	0.06	1.00
	p -	-	-	-	-	-	-	0.00	0.02	0.00	0.02	0.04	0.03	0.63	

P: Calculated probability; r: Person’s correlation coefficient, Exch. Mg: Exchangeable Magnesium, TN: Total nitrogen, Av. Available phosphorus, Av. K: Available potassium, Exch. CO: Exchangeable calcium, OC: Organic carbon



4.0 Conclusion

All in all, conjunctive use of pyrethrum marc and NPK 17-17 is of utmost importance in bush bean farming to increase its yield and improve chemical parameters. Ideally, the use of pymarc at the rate of 10 t ha⁻¹ with 250 Kg ha⁻¹ of NPK 17-17-17 and bush bean spacing of 40 cm x 15 cm can be recommended for better yield of bush beans, optimum use of fertilizers and environmental conservation in the highland volcanic region of Musanze District. However, further research should be carried out in other parts of the country with different combinations of doses in different seasons because soils are quite different in nutrient content.

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5.2 Presentation of the study, findings, and a portion of the work

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5.3 General statement

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5.5 Declaration of interest

The author's thesis is part of the degree "MSc in Soil and Water Engineering" from the University of Rwanda, College of Agriculture, Animal Sciences and Veterinary Medicine. The content, editing choices, document compilation, expressed viewpoints, approval of the final product, and any errors are all the authors' responsibility.

5.6 Conflict of interest

The authors declare no conflict of interest.

6.0 References

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